CLAIMS

1. A system for actively damping the low-frequency coloration of sound comprising:

a listening room including a sound source, said listening room defining at least one mode of low-frequency coloration attributable to said sound source;

an acoustic wave sensor positioned within said listening room, wherein said acoustic wave sensor is operative to produce a first signal representative of said at least one mode of low-frequency coloration;

an acoustic wave actuator responsive to a second signal and positioned within said listening room, wherein said acoustic wave actuator is substantially collocated with said acoustic wave sensor; and

an electronic feedback controller defining an input coupled to said first signal and an output, wherein

said electronic feedback controller is operative to generate said second signal at said output by applying a feedback controller transfer function to said first signal,

said feedback controller transfer function comprises a second order differential equation including a first variable representing a predetermined damping ratio and a second variable representing a tuned natural frequency,

said second variable representing said tuned natural frequency is selected to be tuned to said at least one mode of low-frequency coloration,

said feedback controller transfer function defines a frequency response having a characteristic maximum gain substantially corresponding to the value of said at least one mode of low-frequency coloration, and wherein

said feedback controller transfer function creates a 90 degree phase lead substantially at said at least one mode of low-frequency coloration.

2. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said first signal represents pressure sensed by said acoustic wave sensor and said second signal represents a rate of change of volume velocity to be produced by said acoustic wave actuator.

3. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein

said first signal represents pressure sensed by said acoustic wave sensor,

said second signal represents a rate of change of volume velocity to be produced by said acoustic wave actuator, and wherein

said feedback controller transfer function is as follows:

$$\frac{V(s)}{P(s)} = G\frac{s^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad (1)$$

where the units of $V(s)$ corresponds to said rate of change of volume velocity, $P(s)$ corresponds to the pressure at the location of said acoustic wave sensor and said acoustic wave actuator, s is the Laplace variable, ξ is a damping ratio, ω_n is said tuned natural frequency, and G is a gain value.

4. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein

said first signal represents pressure sensed by said acoustic wave sensor,

said second signal represents a rate of change of volume velocity to be produced by said acoustic wave actuator, and wherein

said feedback controller transfer function is as follows:

$$\frac{V(s)}{P(s)} = G\frac{s}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad (2)$$

where the units of $V(s)$ corresponds to said rate of change of volume velocity, $P(s)$ corresponds to the pressure at the location of said acoustic wave sensor and said acoustic wave actuator, s is the Laplace variable, ξ is a damping ratio, ω_n is said tuned natural frequency, and G is a negative gain value.

5. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein

said first signal represents pressure sensed by said acoustic wave sensor,

said second signal represents a rate of change of volume velocity to be produced by said acoustic wave actuator, and wherein

said feedback controller transfer function is as follows:

$$\frac{V(s)}{P(s)} = G\frac{s(s+a)}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad (3)$$

where the units of $V(s)$ corresponds to said rate of change of volume velocity, $P(s)$ corresponds to the pressure at the location of said acoustic wave sensor and said acoustic wave actuator, s is the Laplace variable, a represents a weighting factor, ξ is a damping ratio, ω_n is said tuned natural frequency, and G is a gain value.

6. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein

said first signal represents pressure sensed by said acoustic wave sensor,

said second signal represents a rate of change of volume velocity to be produced by said acoustic wave actuator,

said feedback controllertransfer function is augmented by the inverse of an acoustic wave actuator transfer function of said acoustic wave actuator to produce an augmented feedback controller transfer function, and wherein

said augmented feedback controller transfer function is as follows:

$$\frac{V(s)}{P(s)} = G\,\frac{s^2 + 2\varsigma_s\omega_s s + \omega_s^2}{s^2 + 2\varsigma\omega_n s + \omega_n^2} \qquad (3')$$

where the units of $V(s)$ corresponds to said rate of change of volume velocity, $P(s)$ corresponds to the pressure at the location of said acoustic wave sensor and said acoustic wave actuator, s is the Laplace variable, ς represents a damping ratio of an acoustic damping controller, ς_n represents a damping ratio of said acoustic wave actuator, ω_n is said tuned natural frequency, ω_s is a natural frequency of said acoustic wave actuator, and G is a gain value.

7. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said feedback controller transfer function defines a frequency response and wherein the gain of said frequency response increases substantially uniformly from a minimum frequency value to an intermediate frequency value to define a characteristic maximum gain and decreases substantially uniformly from said intermediate frequency value to a maximum frequency value.

8. A system for actively damping the low-frequency coloration of sound as claimed in claim 7 wherein said intermediate frequency value corresponds to said at least one mode of low-frequency coloration.

9. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said first variable representing said predetermined damping ratio is a value between about 0.1 and about 0.35.

10. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said first variable representing said predetermined damping ratio and said second variable representing said tuned natural frequency are selected to damp said at least one mode of low-frequency coloration.

11. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said second variable representing said tuned natural frequency is selected to be substantially equivalent to a natural frequency of a target acoustic mode of said at least one mode of low-frequency coloration.

12. A system for actively damping the low-frequency coloration of sound as claimed in claim 11 wherein said target acoustic mode comprises the lowest frequency audible mode of low-frequency coloration.

13. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said second variable representing said tuned natural frequency is selected to be a value between adjacent frequency modes.

14. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said electronic feedback controller is further operative to invert the phase of said second signal.

15. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said acoustic wave actuator introduces characteristic acoustic dynamics into said system and wherein said electronic feedback controller is operative to introduce inverse actuator dynamics into the system.

16. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein

said electronic feedback controller comprises an acoustic damping controller programmed to apply said feedback controller transfer function, and wherein

said acoustic damping controller is configured to selectively damp or treat greater than one frequency mode of coloration.

17. A system for actively damping the low-frequency coloration of sound as claimed in claim 16 wherein said acoustic damping controller is positioned within said enclosure.

18. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said first signal and said second signal comprise respective electric signals.

19. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said acoustic wave actuator and said acoustic wave sensor are positioned to correspond to the location of an acoustic anti-node of a target acoustic mode within said listening room.

20. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said acoustic wave sensor is a microphone.

21. A system for actively damping the low-frequency coloration of sound as claimed in claim 1 wherein said acoustic wave actuator is a subwoofer.

22. A method for actively damping the low-frequency coloration of sound within a listening room including a sound source, said listening room defining at least one mode of low-frequency coloration attributable to said sound source, said method comprising the steps of:

positioning an acoustic wave sensor within said listening room, wherein said acoustic wave sensor is operative to produce a first signal representative of said at least one mode of low-frequency coloration;

positioning an acoustic wave actuator responsive to a second signal within said listening room, wherein said acoustic wave actuator is substantially collocated with said acoustic wave sensor;

coupling an input of an electronic feedback controller to said first signal, wherein

said electronic feedback controller is operative to generate said second signal at an output by applying a feedback controller transfer function to said first signal,

said feedback controller transfer function comprises a second order differential equation including a first variable representing a predetermined damping ratio and a second variable representing a tuned natural frequency,

said second variable representing said tuned natural frequency is selected to be tuned to said at least one mode of low-frequency coloration,

said feedback controller transfer function defines a frequency response having a characteristic maximum gain substantially corresponding to the value of said at least one mode of low-frequency coloration, and wherein

said feedback controller transfer function creates a 90 degree phase lead substantially at said at least one mode of low-frequency coloration;

selecting a value for said first variable representing said predetermined damping ratio;

selecting a value for said second variable representing said tuned natural frequency; and

operating said acoustic wave actuator in response to said second signal.

23. A method for actively damping the low-frequency coloration of sound within a listening room as claimed in claim 22 wherein said value for said first variable and said value for said second variable are selected to damp said at least one mode of low-frequency coloration.

24. A method for actively damping the low-frequency coloration of sound within a listening room as claimed in claim 22 wherein said value for said first variable is selected to be a value between about 0.1 and about 0.35 and wherein said value for

said second variable is selected to correspond to the lowest audible frequency mode of said at least one mode of low-frequency coloration.

25. A system for actively damping the low-frequency coloration of sound comprising:

a listening room including a sound source, said listening room defining at least one mode of low-frequency coloration attributable to said sound source;

an acoustic wave sensor positioned within said listening room, wherein said acoustic wave sensor is operative to produce a first signal representative of said at least one mode of low-frequency coloration, and wherein said first signal represents pressure sensed by said acoustic wave sensor;

an acoustic wave actuator responsive to a second signal and positioned within said listening room, wherein said acoustic wave actuator is substantially collocated with said acoustic wave sensor, wherein said second signal represents a rate of change of volume velocity to be produced by said acoustic wave actuator, and wherein said acoustic wave actuator introduces acoustic dynamics into said system; and

an electronic feedback controller defining an input coupled to said first signal and an output, wherein

said electronic feedback controller is operative to generate said second signal at said output by applying a feedback controller transfer function to said first signal, invert the phase of said second signal, and to introduce inverted actuator acoustic dynamics into said second signal,

said feedback controller transfer function comprises a second order differential equation including a first variable representing a predetermined damping ratio and a second variable representing a tuned natural frequency,

said second variable representing said tuned natural frequency is selected to be tuned to said at least one mode of low-frequency coloration, and wherein

said feedback controller transfer function is selected from the group consisting of

$$\frac{V(s)}{P(s)} = G\frac{s^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad (1),$$

$$\frac{V(s)}{P(s)} = G\frac{s}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad (2), \text{ and}$$

$$\frac{V(s)}{P(s)} = G\frac{s(s + a)}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad (3)$$

where the units of $V(s)$ corresponds to said rate of change of volume velocity, $P(s)$ corresponds to the pressure at the location of said acoustic wave actuator and said acoustic wave sensor, a represents a weighting factor, ξ is a damping ratio, ω_n is said tuned natural frequency, and G is a gain value,

said feedback controller transfer function defines a frequency response having a characteristic maximum gain substantially corresponding to the value of said at least one mode of low-frequency coloration,

said feedback controller transfer function creates a 90 degree phase lead substantially at said at least one mode of low-frequency coloration,

said feedback controller transfer function defines a frequency response having a gain that increases substantially uniformly from a minimum frequency value to an intermediate frequency value to define a characteristic maximum gain and decreases substantially uniformly from said intermediate frequency value to a maximum frequency value, and wherein

said intermediate frequency value corresponds to said at least one mode of low-frequency coloration.

26. A system for actively damping the low-frequency coloration of sound as claimed in claim 25 wherein

said feedback controller transfer function is augmented by the inverse of an acoustic wave actuator transfer function of said acoustic wave actuator to produce an augmented feedback controller transfer function, and whereinsaid augmented feedback controller transfer function is as follows:

$$\frac{V(s)}{P(s)} = G\,\frac{s^2 + 2\varsigma_s\omega_s s + \omega_s^2}{s^2 + 2\varsigma\omega_n s + \omega_n^2} \qquad (3')$$

where the units of $V(s)$ corresponds to said rate of change of volume velocity, $P(s)$ corresponds to the pressure at the location of said acoustic wave sensor and said acoustic wave actuator, s is the Laplace variable, ς represents a damping ratio of an acoustic damping controller, ς_n represents a damping ratio of said acoustic wave actuator, ω_n is said tuned natural frequency, ω_s is a natural frequency of said acoustic wave actuator, and G is a gain value.

27. A system for actively treating noise within a fluid-carrying duct comprising:

a fluid-carrying duct;

a source of acoustical disturbance within said fluid-carrying duct, wherein said acoustical disturbance defines at least one frequency of disturbance within said fluid-carrying duct;

an acoustic wave sensor positioned to sense fluid pressure within said duct, wherein said acoustic wave sensor is operative to produce a first signal representative of said frequency of disturbance;

an acoustic wave actuator positioned to manipulate fluid within the duct, wherein said acoustic wave actuator is substantially collocated with said acoustic wave sensor; and

an electronic feedback controller defining an input coupled to said first signal and an output, wherein

said electronic feedback controller is operative to generate said second signal at said output by applying a feedback controller transfer function to said first signal,

said feedback controller transfer function comprises a second order differential equation including a first variable representing a predetermined damping/treating ratio and a second variable representing a tuned natural frequency,

said second variable representing said tuned natural frequency is selected to be tuned to said frequency of disturbance, and

said feedback controller transfer function defines a frequency response having a characteristic maximum gain substantially corresponding to the value of said frequency of disturbance.

28. A system for actively treating noise within a fluid-carrying duct as claimed in claim 27 wherein the fluid-carrying duct is selected from the group consisting of liquid-carrying ducts, gas-carrying ducts, and combinations thereof.

29. A system for actively treating noise within a fluid-carrying duct as claimed in claim 27 wherein said acoustic wave sensor is a microphone and said acoustic wave actuator is a subwoofer.

30. A system for actively treating noise within a fluid-carrying duct as claimed in claim 27 wherein said acoustic wave sensor is a pressure sensor and said acoustic wave actuator is a diaphragm modulated by an electrical or hydraulic drive.

31. A system for actively treating noise within a fluid-carrying duct as claimed in claim 27 wherein said system is employed in air-conditioning ducts, industrial exhaust stacks and engine intake and exhaust apparatus, or pulsation abatement in liquid-carrying lines.

32. A system for actively treating noise within a fluid-carrying duct as claimed in claim 27 wherein said feedback controller transfer function is arranged to simulate an active, low-pass acoustic filter.

33. A system for actively treating noise within a fluid-carrying duct as claimed in claim 32 wherein said feedback controller transfer function is as follows:

$$LP = Cs^2$$

C represents the compliance of the acoustic system, and *s* is the Laplace variable.

34. A system for actively treating noise within a fluid-carrying duct as claimed in claim 27 wherein said feedback controller transfer function is arranged to simulate an active, high-pass acoustic filter.

35. A system for actively treating noise within a fluid-carrying duct as claimed in claim 34 wherein said feedback controller transfer function is as follows:

$$HP=1/L$$

where L represents the inertance of ports in the system.